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Anomalous Behavior of the Infrared-active *c*-axis Phonons in the Trilayer $Bi_2Sr_2Ca_2Cu_3O_{10}$ Superconductor

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Introduction: It is recognized that the *c*-axis charge dynamics in high-T_C cuprate superconductors is governed by an intrinsic Josephson effect between the weakly-coupled superconducting CuO_2 layers. In examining the anomalous behavior of the far-infrared *c*-axis conductivity of bilayer $YBa_2Cu_3O_{7-\delta}$ (Y123) and $Bi_2Sr_2CaCu_2O_8$ (Bi2212) superconductors in the vicinity of T_C, it has been recently argued [1,2] that even closely spaced CuO_2 layers are weakly coupled. The anomalies of some of the *c*-axis phonons have been explained within a model invoking both the inter- and *intra*-bilayer Josephson effects and variations of the electric field inside the unit cell. To gain further insight into the origin of the coupling, taking place for the closely spaced CuO_2 planes, and its role in determining the charge dynamics of the cuprates, we aim at extending the investigations to the trilayer $Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi2223) superconductor, and comparing the results with those for the single and bilayer compounds.

Methods and Materials: Bi2223 single crystals were grown by the floating-zone technique. Experimental spectra of the *c*-axis dielectric response of as grown underdoped Bi2223 single crystals have been obtained by ellipsometric measurements using a home-build setup attached to a Nicolet Magna 860 FTIR Spectrometer at the U4IR beamline.

Results: Figure 1 shows the real part of the dielectric function $\varepsilon_1(\omega)$ and that of the conductivity $\sigma_1(\omega)$ of the Bi2223 crystal with T_C = 97 K measured at different temperatures. The spectra exhibit the same kind of anomalies related to the superconductivity as in the bilayer Bi2212 [2]. Below T_C the electronic background increases in the frequency region around 550 cm^{-1} and simultaneously the oxygen-bond-bending and the apical oxygen phonon modes at 363 cm^{-1} and 589 cm^{-1} lose a large part of its spectral weight. The principal difference between the phonon anomalies observed in the bilayer and trilayer Bi-systems at T_C is that in the latter system the changes of the spectral weight of the apical phonon mode are much more pronounced and the additional phonon mode, exhibiting the opposite temperature dependence, is observed at 398 cm^{-1}. Our shell model lattice-dynamical calculations show that the additional mode at 398 cm^{-1} manly involves the out-of-phase vibrations of the oxygen ions in the additional middle CuO_2 plane against those in the outer CuO_2 planes. The spectral-weight gain of the mode at 398 cm^{-1}below T_C is naturally explained by variations of the local electrical field acting on the oxygen ions inside the trilayer as the Josephson current sets in.

Conclusions: The anomalous behavior of the c-axis optical conductivity have been observed in the trilayer Bi2223 single crystal at T_C and explained within the model involving the intralayer Josephson effect. This study verifies the relevance of the Josephson couping between closely spaced CuO_2 layers in considering the out-of-plane charge dynamics of the multilayer cuprate superconductors.

References:

[1] C. Bernhard *et al.,* Phys. Rev. B **61**, 681 (2000).
[2] D. Munzar *et al.*, Phys. Rev. B **64,** 024523 (2001).

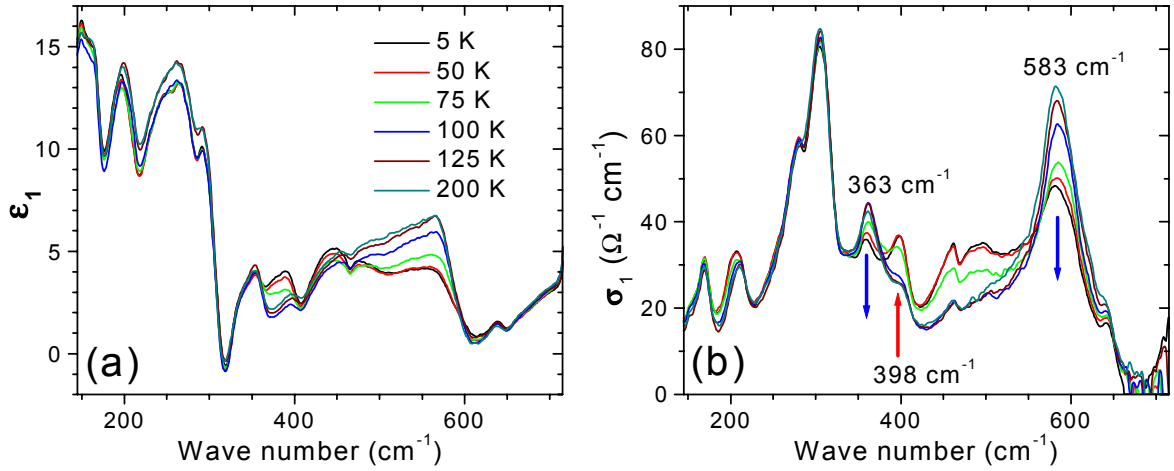

Fig.1. Temperature dependence of the real parts of the c-axis (a) dielectric function $\varepsilon_1(\omega)$ and (b) conductivity $\sigma_1(\omega)$ in the Bi2223 crystal, T_C = 97 K,